DSP DESIGN EDUCATION AT GEORGIA TECH

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ABSTRACT

Digital signal processing (DSP) has made significant impact on the fields of telecommunications, medical technology, information storage and retrieval, military applications, remote sensing, and man-machine communications. The DSP Laboratory at Georgia Tech is heavily involved in research and education in this important area. This paper discusses the state-of-art DSP software and hardware design education (graduate, undergraduate, and continuing education) being offered by our laboratory, and outlines the guiding principles and rationale that continue to shape our closely intertwined research and education goals. Recent curriculum changes at Georgia Tech are also discussed.

1. INTRODUCTION

The DSP Laboratory at Georgia Tech houses 11 faculty, four research scientists, a few adjunct faculty and post-doctoral scholars, and over 70 doctoral students in a state-of-art environment consisting of over seventy workstations, distributed access to 80 Gbytes of data storage, advanced video signal processing and real-time rapid prototyping hardware infrastructure together with a modern software design environment. In a typical year consisting of four academic quarters, the Laboratory offers 8–10 courses related to signal processing at the undergraduate (BS) level, and up to 10 advanced DSP courses at the graduate level (MS/PhD).

2. GUIDING PRINCIPLES

Since the Laboratory's inception, we have adopted the principle that a strong education program benefits from a productive research program. In return, the strong educational program further strengthens the research program by providing excellent graduate students and a means for technology transfer to industry. Following this principle, we have recently extended our course offerings significantly at the undergraduate level by adding design courses spawned by our research activities. We now offer an undergraduate specialization in DSP consisting of 5 courses which culminate in design projects involving implementation of DSP algorithms for real-time processing and/or application-specific VLSI design. The graduate DSP curriculum has also been similarly enhanced.

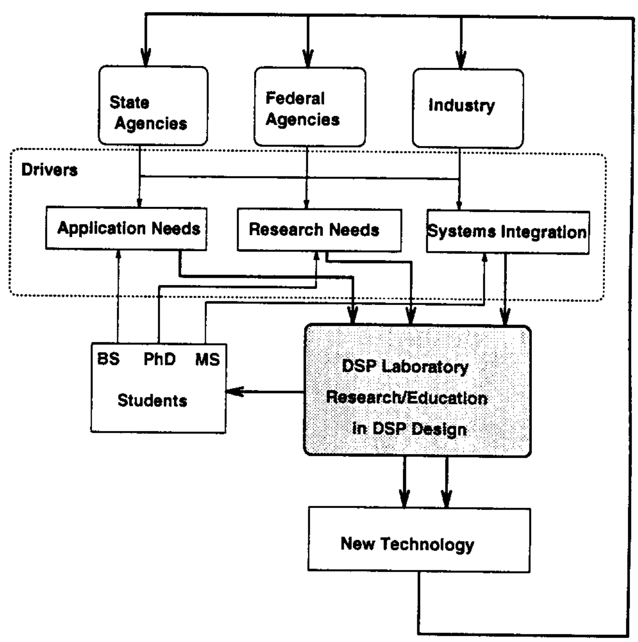

Fig 1. The interaction between educational and research programs, technology drivers and resource needs at Georgia Tech's DSP Laboratory.

The synergistic interaction between teaching and research, their drivers and end-results is depicted in Fig. 1. The drivers of the research program are industry, as well as state and federal government agencies. These drivers can be classified into those of *resource* needs (e.g., qualified personnel) and *technology* related issues. Resource needs can be further classified into three types — (1) design and application engineers, (2) system integrators and managers, and (3) research and development engineers. These needs are met by BS, MS, and PhD graduates, respectively. Thus our undergraduate and graduate education curricula have been developed to provide an appropriate level of training at the BS, MS, and PhD levels. We classify technology drivers (from the industry and the government) into one of the following five categories of applications as adapted from a 1994 report by the Semiconductor Industry Association:

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DSP Design Technology Drivers:

1. *Commodity DSPs*: Valued at less than $300, these include CD players, recorders, VCRs, facsimile and answering machines, simple signal processing filtering packages, etc, primarily aimed at the highly competitive mass-volume consumer market.
2. *Portable DSPs*: Valued at less than $800, these include portable and hand-held low power electronic products for man-machine communications, digital audio, security systems, modems camcorders, industrial controllers, scanners, communications equipment, DSP boards, etc.
3. *Cost-Performance Products*: Valued at less than $3000, these products trade off cost for performance, and include DSP products such as video teleconferencing equipment, telecommunications switches, laptops, audio, high performance DSP boards and co-processors, and DSP CAD packages for hardware/software design.
4. *High Performance DSP Products*: Valued at over $8000, these products include high-end workstations with DSP co-processors, real-time signal processors, digital HDTV, radar signal processor systems, avionics and military systems, sensor and data processing hardware and software systems.
5. *Robust DSP Products*: ,These are primarily for automotive (under-the-hood) and hostile environments.

Traditional DSP educational programs in the past have primarily concentrated on the area of high performance DSP products (primarily in algorithm design and evaluation, with little emphasis on hardware design or implementation issues). However, the highly competitive and global nature of the marketplace has caused a shift in this focus, with challenges for rapid design, high quality, and low cost being required for all five product categories. A strong educational and research program in DSP must, therefore, meet these resource and technology needs effectively and in a timely manner, given the rapid changes in the industrial and governmental sectors. Thus the research focus is changing from purely theoretical areas to more practical design challenges that are just as intellectually demanding. Our educational program reflects this changing focus, in an effort to meet the demands of our technology drivers.

3. DESIGN EDUCATION DRIVERS

We will now discuss a few specific drivers that continue to shape DSP hardware/software design curriculum at Georgia Tech's DSP Laboratory.

3.1. ARPA's RASSP Program

The Rapid Prototyping of Application Specific Signal Processors (RASSP) is an ARPA (Electronic Systems Technology Office) and US Department of Defense initiative intended to dramatically improve the way complex digital systems, particularly embedded digital signal processors, are designed, manufactured, upgraded, and supported. The target RASSP improvement is at least a four-fold reduction in the time to go from design concept to fielded prototype. Equivalent improvements in cost and quality are also targets. The motivation for the RASSP initiative is the pervasive need for affordable embedded signal processors that are state-of-the-art when they are fielded rather than when they are first defined [1].

An important RASSP goal is that the technology be adopted by industry and continue to evolve after the initiative is completed. A novel Educator/Facilitator (E/F) program leads this technology transition process. The E/F effort is led by SCRA, with the DSP Laboratory providing technical leadership through short courses. The new course material developed for technical training of the various industry participants will also be used in our undergraduate and graduate design curriculum.

In the area of the development of a RASSP education program, our design education program is aimed at the design of electronic systems that typically have one or more boards, a variety of implementation technologies and interfaces, and a wide range of data rates. Since this is an extremely broad area, the strong RASSP focus on a specific problem domain (signal processing) is needed to keep the goals achievable. The overall technical approach is to coordinate improvement efforts in signal processor architecture, design methodology, and electronic design infrastructure. Infrastructure includes such items as design automation, reuse libraries, and enterprise integration.

A new undergraduate senior-level DSP elective course (EE 4173, to be offered in 1995) and two graduate level courses (offered Winter/Summer 1994) will be directly influenced by the RASSP program and its technological derivatives. Please refer to [1] for more information on the RASSP education curriculum being developed at the DSP Laboratory. Three more graduate HW/SW design courses and five industrial short courses are under development. These courses will be provided to other universities planning to upgrade their design education curriculum.

3.2. NSF's VSP Design Project

Over the past twenty years the Digital Signal Processing (DSP) Laboratory at Georgia Tech has engaged in extensive research into defining optimal multiprocessor architectures for certain classes of DSP algorithms [2], under sponsorship from the Joint Services Electronics Program (JSEP) and the National Science Foundation (NSF). This research has resulted in several compilers designed to generate optimal schedules for algorithms given specific architectural properties of the target multiprocessor. It has also resulted in the design of four multiprocessors, three of which were constructed. More recently (in 1993) NSF provided funding to the DSP Laboratory for the design of a Video Signal Processor (VSP) for real-time video applications, the Chameleon. The Chameleon is a 64-processor distributed-memory system with a fully configurable communications architecture. It has been designed to fulfill several functions in a very cost-effective system. It will provide a testbed for ongoing research and education on parallel DSP algorithms, architectures and compilers; it will provide a general-purpose asynchronous multiprocessor for more widely-based research into multiprocessor architectures and algorithms; and it will provide the capability to process video and audio in real time. Other applications include processing of space-time adaptive processing techniques in the processing of radar images, simulation of large event-driven systems, and processing of seismic imaging data. This project has significantly influenced the DSP hardware and software teaching and instructional environment. The graduate level course in DSP Architectures (EE 6417) has been directly influenced through this continuing multiprocessor effort, and now the development of the new undergraduate course (EE 4172) will address some of these issues for real-time DSP applications.

3.3. ARPA's Mountaintop STAP Project

In an application arena, one research project with a strong connection to the graduate educational program is in the area space-time adaptive processing (STAP) for airborne radars. In particular, this program is well supported by graduate courses in Array Processing (EE 6419) and Radar Signal Processing, as well as topics in the undergraduate course on Applications of DSP (EE 4171). The primary objective of this research is the development of practical algorithms for real-time adaptive nulling and clutter rejection to facilitate target identification in airborne arrays. The computational demands of the problem are immense due to the requirement for simultaneous processing in three dimensions: range, doppler and direction. One element of this program is the marriage of mathematical techniques for adaptive processing with implementation on parallel computer architectures. The computational demands and data rates found in an adaptive space-time beamforming system are so severe that one must resort to very high-speed machines; however, the machine capabilities are limited by the size and power restrictions imposed on an airborne platform. The interaction between algorithms, architectures and implementations is an important theme that we are must address in the education process related to design. On one level, students must be aware of the hardware trade-offs that put limits on what is reasonable in an algorithm; on another level, they must learn to use specific design methods and computer-aided tools for simulating an algorithm and then creating its implementation rapidly; and finally, some students must be involved in the creation of those design tools. The STAP research provides an excellent opportunity to explore the first two issues through environments such as MATLAB, Khoros, and Ptolemy, and then take advantage of results developed in the rapid-prototyping research which seeks to provide a virtual hardware testing environment.

4. UNDERGRADUATE CURRICULUM

In the past year, the EE curriculum at Georgia Tech has been restructured into a two-tier system: fundamental courses taken by all Sophomore and Junior level students, followed by an "Area of Specialization" consisting of 4–5 courses molded around a Senior design project course, or courses. A number of Areas of Specialization have been created, corresponding roughly to the major research areas within the School of Electrical and Computer Engineering. One of these is a DSP specialization tailored for undergraduates. In this regard, our curriculum is unique in that we offer in-depth training in DSP to undergraduates. In the past, we had always encouraged certain undergraduates to enroll in the graduate courses if they wanted to learn more about DSP before entering graduate school. Now, the area of specialization changes our focus a bit, because we have defined a new sequence of courses that leads into DSP design projects, rather than just more theory as found in graduate classes. Among the courses listed below, the area of specialization consists of the courses: EE 3340, 4078, 4170, 4171, 4172 and 4173. The design flavor is emphasized in two implementation courses: EE-4172 which concentrates on algorithms for real-time implementation, and EE-4173 which treats rapid prototyping and VLSI design synthesis. Both of the design courses will involve design teams consisting of students with varied backgrounds and interests: applied math, applications, commercial marketability, and computer engineering.

4.1. Role of Computer Engineering

The role of computer engineering students and their training is also well represented in our new design courses. Since the implementation side of DSP design is relies on a sound understanding of computer architecture, or real-time I/O interfacing, or VLSI systems design, the background needed by undergraduates interested in DSP design is somewhat removed from the traditional EE background, and also a bit separate from the Applied Math orientation of typical DSP students who want to continue on into graduate school. In this regard, we have taken two steps in recent curriculum revisions to bolster the computer engineering background of our students. First of all, in the EE curriculum we now require two introductory CS courses, as well as a course in digital logic design, and one in basic computer architecture. These will provide the average EE student with a rudimentary background needed to participate in the type of implementation courses that we have created for our area of specialization.

In another curriculum move, we have been active in the redefinition of the curriculum for the Computer Engineering degree. All computer engineering students must now take a new signals and systems sequence that starts with a Sophomore course in discrete-time systems (i.e., a taste of DSP), is followed by a traditional circuits course, and ends with a course in the theory of the Fourier transform. This approach has two benefits: first, computer engineering students see, in their first EE course, the relationship between an application area (DSP) and computer simulation/implementation; second, some students are tempted to pursue DSP as the logical outgrowth of their interest in computers. Students coming from this second motivation will provide our DSP program with a stronger link to implementation. With more and more work being done at the level of using DSP modules as part of a computer-aided design environment, we see this strategy as beneficial in the training of students who pick DSP as an undergraduate "major."

4.2. Brief Course Descriptions

The undergraduate DSP curriculum provides a solid foundation in DSP software and hardware design in addition to the fundamentals of DSP through the following ECE courses:

EE 2200: Introduction to Discrete Time Systems. Analysis of discrete-time systems, block diagram representation of systems. Computer-aided analysis and simulation of basic DSP applications via MATLAB.

EE 3230: Signals and Systems. Fourier Analysis and its applications to modulation and filtering. For Computer Engineering majors only.

EE 3212: Signals and Systems I. Theory of signals and LTI systems. Fourier Analysis and applications to modulation and filtering.

EE 3213: Signals and Systems II. Laplace and Z transforms for analysis and design of circuits and systems. Sampling.

EE 3340: Random Signals and Noise. Probability. Random variables. Autocorrelation and power spectrum.

EE 4078: Digital Signal Processing. Introduction to the theory and application of DSP. Frequency analysis and DFT. Random signals. Digital filter structures and design.

EE 4170: DSP Laboratory. Computer-based tools [4] for filtering and frequency response. Algorithm design. FFT, spectrum analysis and filter design.

EE 4171: Applications of DSP. Applications of DSP to speech, image, radar and adaptive filtering. Emphasis on computer-based SW design and implementation of DSP systems for various applications [4].

EE 4172: Real-time DSP Implementation. Programmable DSPs and SW Design environments. Assembly code development, real-time I/O and embedded DSP design within a host environment.

EE 4173: Design Synthesis of Application-Specific DSPs Specification and prototyping of DSP systems. Virtual prototyping methodologies for DSP design, architectural optimization, VLSI design synthesis, VHDL-based design using Synopsys, Mentor, and Compass design automation tools.

5. GRADUATE CURRICULUM

The graduate curriculum, which has traditionally been very strong, has been further enhanced by applications and implementation (SW/HW) course sequences in the past few years [3]. The graduate DSP design curriculum consists of the following courses:

EE 6413: Digital Filters. Design, implementation and application of DSP algorithms.

EE 6414: Advanced DSP. Advanced topics including: parametric signal modeling, Wiener filtering and power spectral estimation.

EE 6415: Digital Processing of Speech Signals. Application of DSP to design of Speech Applications.

EE 6416: Multidimensional DSP. Introduction to the theory and applications of multidimensional DSP.

EE 6417: VLSI Architectures for DSP. Design of DSP multiprocessors, design and prototyping of DSP algorithms, RASSP technology.

EE 6418: Digital Image Processing. Image Coding, restoration, and enhancement.

EE 6419: Spatial Array Processing. Theory of space-time signals, adaptive beamforming.

EE 6410: Adaptive Filters. LMS and Recursive Least Squares. Convergence. Applications.

EE 6420: Time-Frequency Representations for Signal Processing. Filter-bank analysis/synthesis design techniques.

EE 6421: Morphological Signal Processing. Non-linear meth ods for image and signal representation based on mathematical morphology.

EE 834x: Radar Signal Processing and Detection. Algorithm design for radar signal processing.

EE 834y: Rapid Prototyping of Application Specific Signal Processors. Advanced RASSP methodologies, VHDL-based system design and verification using Synopsys, Mentor, and Compass design automation tools.

6. SUMMARY

This paper describes in brief the guiding principles that motivate the DSP design education content of our curriculum at the DSP Laboratory at Georgia Tech. Recent technology drivers that have influenced our design curriculum are described, together with a concise snapshot of our undergraduate and graduate course sequences.

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